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DIASTROPHISM AND THE FORMATIVE PROCESSES. VII

PERIODICITY OF PALEOZOIC OROGENIC MOVEMENTS

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INTRODUCTION

Within the last few years there has been a growing belief among American geologists that diastrophism, in its greater manifestations, has been periodic, rather than continuous. According to this view the earth has passed through periods of diastrophic activity alternating with periods of relative quiescence.¹ During the more protracted of the periods of quiescence the earth's surface is believed to have remained stable sufficiently long to allow base-leveling to much an advanced stage, and this is held to imply stability, for, without stability in the outer portion of the earth, mature base-leveling is scarcely possible. During such a time of base-leveling, stresses within the body of the earth must be accumulating steadily, but because of the high rigidity now apparently demonstrated these stresses show little outward manifestation of their presence for a long time, until finally, according to this view, the increasing internal stresses reach such an intensity that the mass of the earth can resist no longer but yields, and a period of active deformation succeeds the state of crustal inactivity. The deformation once inaugurated continues till the stresses are essentially eased. Then another period of quiescence sets in, to be followed in turn, after a long interval during which new stresses have developed, by another deformative outbreak.

Such diastrophic movements are held to be in themselves major events in the earth's history; and, in addition, they are the direct

¹ T. C. Chamberlin and R. D. Salisbury, *Geology*, III (1906), 192, 193; T. C. Chamberlin, "Diastrophism as the Ultimate Basis of Correlation," *Jour. Geol.*, XVII (1909), 685-93; Charles Schuchert, "Paleogeography of North America," *Bull. Geol. Soc. Am.* XX (1910), 427-606; Bailey Willis, "Principles of Paleogeography," *Science*, XXI, No. 790 (1910), 246-49; E. O. Ulrich, "Revision of the Paleozoic System," *Bull. Geol. Soc. Am.*, XXII (1911), 281-680.

cause of extensive changes in sedimentation; and these, together with climatic and other effects that follow, influence profoundly the life-development. Thus, back of both stratigraphy and paleontology lies diastrophism, which furnishes the conditions upon which they depend.¹ If periods of diastrophism are thus truly the ultimate basis of correlation, they form a subject of inquiry of prime importance.

The chief purpose of the study upon which this paper is based is to determine to what extent past diastrophic movements of the higher order actually have taken place—simultaneously in different parts of the globe and periodically in the same region—with a view to the bearing of the facts on the determination of systems and periods, and on the broader correlations of geologic events. It is an attempt to test the hypothesis that the geologic periods represent, in the main, periods of relative quiescence, during which there were sea-transgressions and widespread sedimentation, and that they were separated one from another by diastrophic disturbances of shorter duration. The study is an attempt to discover whether the principal manifestations of diastrophic activity in one portion of the globe can be correlated approximately with corresponding disturbances in other parts of the globe, and whether the synchronous disturbances have been sufficiently widespread and effective in their manifestations to constitute a satisfactory basis for dividing geologic time into periods.

There can be little doubt that there are various grades of deformation and that most or all of these are serviceable as markers of time divisions of some order, but in the present discussion I shall try to limit the deformations recognized to those that involve some notable folding, or at least to unconformities so marked as to imply notable warping somewhere. This paper will be further limited in that it offers merely a preliminary selection of data relative to earth movements of the Paleozoic era that have been gathered from various accessible sources but not yet fully traced to their original sources and critically examined. The data are a part of a more general collection which includes the Mesozoic and Cenozoic eras. The present paper is but a modification of one read at the Twelfth

¹ T. C. Chamberlin, "Diastrophism as the Ultimate Basis of Correlation," *Jour. Geol.*, XVII (1909), 692.

International Geological Congress at Toronto in August, 1913, and is presented here because it was undertaken as a part of the series of studies now appearing under the title "Diastrophism and the Formative Processes."

For brevity in designating the various diastrophic disturbances, my father has found it convenient in his lectures to use such terms as the following: Ordovicides for foldings or strong diastrophic movements which took place either at or near the close of the Ordovician period; Silurides for like movements at or near the close of the Silurian period; and similarly, Devonides, Carbonides, and Permides for movements connected with the closing stages of the Devonian, Carboniferous, and Permian periods. For movements near the close of the Mississippian, or Lower Carboniferous period, the term Culmides is used in place of a more cumbersome derivative from the name Mississippian. These terms will be used in this paper.

CAMBRIDES ?

The Proterozoic era seems to have closed with profound diastrophic movements in most parts of the world where satisfactory identifications have been made. At the close of the era the sea was quite generally withdrawn into the deep basins. The Paleozoic era which followed commenced with advancing seas in which the Cambrian sediments were laid down unconformably, for the most part, upon eroded and trunkated Proterozoic strata. During the Cambrian period there appears to have been a general, but more or less fluctuating, advance of the sea up to the close of what is usually classed as Upper Cambrian. Following this, in the debatable ground that lies between the well-recognized Upper Cambrian and the undoubted Ordovician, evidence of some diastrophic movements appears, but, so far as present data go, these movements do not seem to be of the decided class to which this paper chiefly relates. Rather widespread unconformities occur near this horizon in various parts of the Mississippi and St. Lawrence basins, but they are not of such a nature as seriously to affect the general parallelism of the Cambrian and Ordovician systems.¹ There are discordances be-

¹ Chamberlin and Salisbury, *Geology*, II (1906), 311-12; Ulrich, "Revision of the Paleozoic System," *Bull. Geol. Soc. Am.*, XXII (1911), 614-16, 626-28; Schuchert, "Paleogeography of North America," *ibid.*, XX (1910), 522-29.

tween the Cambrian and Ordovician in Bohemia, in certain parts of the Armorican massif,¹ in the north of Wales,² in Norway,³ and at Spiti in the Himalayas,⁴ but no clear evidence of important folding appears. It is not clear that any one of these unconformities is of the higher order; they seem rather to be intercurrent movements of the minor order in what was, in general, a time of crustal quiescence. In general much hesitation and indecision has been shown by geologists in determining where to draw the dividing line in the transition series between the Cambrian and the Ordovician. In this study it is the periods of pronounced crustal crumpling, or of marked differential movement, that are especially sought as unequivocal representatives of events of the first order of importance; for unconformities of the simpler order are liable to represent events of a minor order of importance. Judged by this rather severe standard, the transition from the Cambrian to the Ordovician was relatively quiet; it does not now appear that there were pronounced crustal movements, and hence, on the basis chosen, it does not seem clear that the two were sharply separated periods in the earth's history. Throughout most of the globe where evidence is available, there was no radical change in the areas or the attitudes of sedimentation. This indecisiveness in the character of the diastrophic movements associated with the close of the Cambrian and the opening of the Ordovician leaves the question of the separateness of the two as distinct periods a somewhat open one considered from the diastrophic basis simply.

ORDOVICIDES

The greater part of the Ordovician period seems to have been a time of crustal quiescence, in the sense of the term used in this discussion, but its closing stages were marked by pronounced disturbances in various portions of the globe. These are the first crustal deformations of the higher order for which I have found clear evidence since the close of the Proterozoic.

¹ Emile Haug, *Traité de géologie*, II (1911), 634-35.

² A. J. Jukes-Browne, *The Building of the British Isles* (1911), p. 78.

³ Eduard Suess, *The Face of the Earth*, Sollas trans., II (1906), 52.

⁴ A. de Lapparent, *Traité de géologie*, 5th ed., II (1906), 808.

In North America the disturbances occurred principally on the eastern side. A portion of the Atlantic border was strongly folded. According to Campbell, the general region lying eastward from what is now the Appalachian Valley, throughout much of its extent, was subject to disturbing influences at several periods during the Paleozoic.¹ This is in accord with the view that the source of the vast quantity of clastic sediment which was laid down in the Appalachian geosyncline in the course of the Paleozoic was the old land of Appalachia lying between the present mountains and the edge of the continental shelf. So great a volume of the sediments derived from this not very extensive land area is thought to imply a repeated renewal of the land by uplift.

Definite evidence of one such disturbance is found in the Taconic Mountains of western New England and the adjacent portions of New York and Canada. In this region the Cambrian and Ordovician strata are sharply folded and faulted while the Silurian strata rest unconformably upon the flanks of these folds and are not incorporated in them.² Today only the obscure stumps of these ancient mountains are visible, but they seem once to have constituted a great range. Thrust faulting, not unlike that of the southern Appalachians, was prominent but perhaps on a somewhat smaller scale.³

This ancient chain of mountains extended far to the northeast, paralleling the present coast. A large tract in northeastern Maine, northwestern New Brunswick, and the Gaspé Peninsula is occupied by a broad synclinorium of Silurian strata which appear to lie unconformably upon folded and eroded Cambrian rocks.⁴ From Maine the eastern margin of the Silurian extends northeastward across New Brunswick to the Bay of Chaleur. In surveying the line between the Cambro-Ordovician and the Silurian, Bailey found

¹ M. R. Campbell, "Paleozoic Overlaps in Montgomery and Pulaski Counties, Virginia," *Bull. Geol. Soc. Am.*, V (1894), 178-79.

² James D. Dana, *Manual of Geology*, 4th ed. (1895), p. 386.

³ C. D. Walcott, "The Taconic System of Emmons," *Am. Jour. Sci.*, 3d Ser., XXXV (1888), 315-20; James D. Dana, *op. cit.*, p. 528.

⁴ L. W. Bailey and William McInnes, "Explorations in New Brunswick, Quebec and Maine," *Ann. Rept. Geol. Surv. Canada*, New Ser., III (1889), 29-31 M.

"incontestable evidence of discordance along its whole length."¹ The fossiliferous Silurian slates are marked by a heavy basal conglomerate whose pebbles have been derived from the Cambro-Ordovician strata, but it is not clear how much time is represented by the unconformity.

The width of the belt affected by the movement may have been considerable. In southern Quebec, southeast of the St. Lawrence River, isolated areas of Silurian strata, largely limestones, occur in some of the synclines, and these Silurian beds are found to lie unconformably upon Ordovician strata, indicating that this region also was affected by the movement.² But the effects of the uplift were not felt upon the north side of the Gulf of St. Lawrence, for on Anticosti Island the accumulation of the great limestone formation which commenced in Ordovician times continued without a break into the Silurian.³

From the region of the Taconic Mountains of New England and New York evidences of this uplift may be traced southwestward. What appear to be evidences of the same disturbance have been noted on the east side of the Appalachian Mountains as far south as Virginia.⁴ In 1892, N. H. Darton found some crinoids, which Walcott has assigned to the Upper Ordovician, in the slate quarries at Arvon, in the Piedmont region of Virginia.⁵ While the age of the deformation and metamorphism of these rocks is not established, Dana nevertheless regarded this strip as possibly a part of a long Westchester Taconic range which passed just west of Philadelphia and Baltimore.⁶ Very possibly also a portion of the folding of early Paleozoics in New Jersey may belong to the Taconic movement. But here again the age of the folding has not been definitely placed.

¹ L. W. Bailey, in G. M. Dawson's *Summary Rept., Geol. Survey of Canada*, XIII (1900), 146-48 A.

² R. W. Ells, cited by Willis, "Index to the Stratigraphy of North America," *Prof. Paper* 71, *U.S. Geol. Survey* (1912), p. 250.

³ W. B. Scott, *An Introduction to Geology* (1907), p. 567.

⁴ M. R. Campbell, "Paleozoic Overlaps in Montgomery and Pulaski Counties, Virginia," *Bull. Geol. Soc. Am.*, V (1894), 189.

⁵ N. H. Darton, "Fossils in the 'Archean' Rocks of Central Piedmont Virginia," *Am. Jour. Sci.*, 3d Ser., XLIV (1892), 50-52.

⁶ J. D. Dana, *op. cit.*, p. 532.

In the northwestern portion of the state, where the Silurian strata are present to aid in correlation, this critical time period is represented by an extensive unconformity, but there has been no folding there. But that is distinctly west of the Taconic belt.¹ Kümmel discusses the matter thus:

Contrary to long-prevalent and apparently well-established belief, the lower and middle portions of the Silurian system are not represented in New Jersey. Their absence in this and adjoining regions is indicative of somewhat widespread earth movements, unaccompanied in this region by folding, which closed the period of deposition indicated by the Martinsburg sediments, or possibly overlying beds afterward removed by erosion, and raised the region above the zone of sedimentation. When deposition began again, late in Silurian time, beds of coarse conglomerate were laid down. . . .

This is the Shawangunk formation between which and the Martinsburg shale there is a gap representing the upper part of the Ordovician and all of the Silurian below the Salina of the full New York section, but there is no marked divergence of dip and strike where the two formations outcrop in proximity.²

In general, throughout most of the Appalachian province the youngest Ordovician (Richmond) beds are lacking, and an angular discordance between the Ordovician and Silurian at many points implies an emergence corresponding to the Taconic folding to the northeast. Ulrich states that at this time the whole Appalachian region was considerably elevated and the middle and eastern parts of Appalachia itself most probably subjected to profound orogenic movements.³ Dana in particular has urged the magnitude and importance of this early mountain development. Because evidences of this movement, which was so intense in New England and New York, have been recognized over a much wider area, he regarded the Taconic Range of western New York as only one in a great Taconic system of mountains.⁴ This great system lay entirely

¹ Stuart Weller, "The Paleozoic Faunas of New Jersey," *Geol. Survey of New Jersey, Rept. on Paleontology*, III (1902), 54.

² H. B. Kümmel, "Geological Section of New Jersey," *Jour. Geol.*, XVII (1909), 356-57.

³ E. O. Ulrich, "Revision of the Paleozoic System," *Bull. Geol. Soc. Am.*, XXII (1911), 436-37.

⁴ James D. Dana, *Manual of Geology*, 4th ed. (1895), pp. 531-32.

to the east of the present Appalachians, more or less paralleling that later system as it does the coast. This Ordovician system may be regarded as a forerunner of the late Paleozoic Appalachians.

The local stratigraphic details in various portions of this general region, and the great extent of the emergence at this time are clearly pictured in the time scale for eastern North America given by Ulrich and Schuchert in their paper on Paleozoic seas and barriers in eastern North America.¹ It is the view of these authors that the disturbance was felt first in the southern portion of the Appalachian region and progressed thence northeastward along the axis of folding and westward toward the Mississippi basin, and so they believe it was not quite synchronous throughout the entire region affected. In the Lenoir basin (comprising the Athens and Knoxville troughs) the emergence followed the deposition of the Sevier shale, while in the Mississippi basin they regard the main emergence as having followed the Richmond, the time of the maximum uplift. The movement appears to have commenced with several minor pulsations in the closing stages of the Ordovician (Lorraine and Richmond) which quickly led to the great Taconic revolution which terminated the Ordovician, and which was one of the greatest movements in North American Paleozoic history. According to Ulrich and Schuchert, this revolution affected all North America, there being perhaps land throughout from Richmond to Oneida time. But the length of this land interval they believe cannot be satisfactorily ascertained as there are no Mississippi basin sea deposits by which its duration may be measured.

It appears quite widely in the literature that the Cincinnati Arch and Nashville Dome, in Ohio, Indiana, Kentucky, and Tennessee, originated also at this time. The basis for this view has been the widespread unconformity at the base of the Silurian. The Clinton follows the Ordovician and contains in its basal member rounded fragments of the Ordovician rocks² which suggests that the primary uplift of these domes may have been a feature of the Ordovician movement. Foerste, however, regards the evidence for

¹ E. O. Ulrich and Charles Schuchert, "Paleozoic Seas and Barriers in Eastern North America," *Bull. LII, New York State Museum* (1901), p. 658.

² Bailey Willis, *op. cit.*, p. 232.

the origin of the Cincinnati geanticline at this time as inconclusive, and, instead, places its inception between the Niagaran and the Middle Devonian, while it is recognized that the geanticline owes its present proportions to later upwarping which occurred probably in post-Mississippian times.¹ Minor oscillations and tilting, according to Ulrich, occurred in the region of the Cincinnati and Nashville domes much earlier (during the Ordovician period) but these movements were not of the more pronounced type.²

In North America the principal orogenic disturbances of the early Paleozoic thus occurred near the close of the Ordovician and were located near the Atlantic border where thick sediments had been accumulating. Europe seems to have behaved similarly. Throughout much of continental Europe the relatively quiescent conditions of the Ordovician continued with little interruption into the Silurian. But in the British Isles, where the Cambro-Ordovician strata are very thick, there were pronounced orogenic movements which were approximately contemporaneous with the Taconic revolution of North America. Over large areas the Lower Silurian rocks were upheaved, more or less contorted, and in many places suffered a great amount of denudation before the deposition of the Upper Silurian strata began.³ A large portion of the British Isles became land, and Jukes-Browne believes that this continental land included also a large part of the North Sea and nearly the whole of Norway.⁴ The results of this disturbance are conspicuous in the original tract of Siluria (western England and the adjacent portion of Wales) where a decided unconformity separates the Ordovician from the Silurian. In some places the latter extends across the truncated edges of the former, group after group, till they rest directly upon the Cambrian beds. Ramsay's diagram of the section between Church Stretton and Chirbury in Shropshire shows nearly horizontal Llandovery (basal Upper Silurian) beds cutting across nearly

¹ A. F. Foerste, "The Ordovician-Silurian Contact in the Ripley Island Area of Southern Indiana, with Notes on the Age of the Cincinnati Geanticline," *Am. Jour. Sci.*, 4th Ser., XVIII (1904), 321-42.

² E. O. Ulrich, *Bull. Geol. Soc. Am.*, XXII (1911), 416-19.

³ A. C. Ramsay, *The Physical Geology and Geography of Great Britain*, 6th ed (1894), p. 74.

⁴ A. J. Jukes-Browne, *The Building of the British Isles* (1911), pp. 94, 97.

vertical Cambrian and Ordovician strata.¹ It is evident, therefore, that in this region considerable disturbance and extensive denudation followed the Ordovician and preceded the commencement of the Silurian sedimentation.²

Of the events in Asia at this time much less is known. But it is known that in the eastern portion of that continent the Ordovician seas withdrew late in the period, leaving large areas emerged in Mongolia and Manchuria³ and probably also in northern China where the Ordovician is terminated by unfossiliferous dolomites which were probably lagoon deposits. The Silurian has not yet been recognized above them and very likely was never laid down there.⁴ But we have as yet no good evidence of any pronounced mountain-making movements in Asia at this time.

In the Andine region of South America there is a suggestion of diastrophic movements following the Ordovician, for the Silurian is often lacking there, the Devonian resting directly upon the Ordovician.⁵

The eastern portion of the Australian continent was the locus of mountain-making movements at several periods during the Paleozoic. In New South Wales, the close of the Ordovician was attended by both volcanic and diastrophic disturbances. Süssmilch states that at Tallong, the one place where a junction between the Ordovician sediments and those of the next period has been observed, a well-marked unconformity occurs. The evidences of this region are interpreted by Süssmilch as showing that at the close of the Ordovician period there occurred extensive earth movements by which the marine sediments and volcanic ash, which had accumulated to a thickness of many thousands of feet, were pressed into a series of folds trending approximately north and south, and that these suffered denudation so that when the sea readvanced upon these land areas in Silurian time, the new sediments were deposited unconformably upon the trunkated edges of the Ordovician strata.⁶

¹ A. C. Ramsay, *op. cit.*, p. 77.

² Sir Archibald Geikie, *Textbook of Geology*, 4th ed., II (1903), 953.

³ A. de Lapparent, *Traité de géologie*, 5th ed., II (1906), 807.

⁴ Emile Haug, *Traité de géologie*, II (1911), 653.

⁵ *Ibid.*, p. 657.

⁶ C. A. Süssmilch, *Geology of New South Wales* (1911), p. 18.

These evidences of pronounced folding movements in different quarters of the globe at the close of the Ordovician are supported by the extensive withdrawals of the sea from the line of maximum transgression in the mid-Ordovician, to the shore lines implied by the early Silurian beds in many other regions which were not affected by the more violent disturbances. This was a time of general disturbance; but it remains for future study to establish just how nearly synchronous these widespread disturbances were.

SILURIDES

During the greater part of the Silurian period there was a relative freedom from diastrophic disturbances of the major sort. But toward the close marked disturbances set in and may be said to have terminated the epicontinental phase of the Silurian sedimentation in various parts of the globe. North America was affected chiefly by movements of the milder sort but certain portions of Europe suffered from intense orogenic deformation. In North America a comparatively rapid emergence of the continent began with the Guelph and continued until the Silurian period closed with the land nearly as extensive as it was at the beginning of the period, when most of the North American continent stood above water.¹ While the very widespread unconformities indicate a general epeirogenic movement at this time, or else a withdrawal of the sea, or both, very little evidence of pronounced folding has as yet been found on the mainland of this continent. Some slight folding, however, has been recognized on the Atlantic border. Campbell, in a summary of the periods of Appalachian folding in Virginia, has described a deformative movement which, preceding the deposition of the Walker black shale, has folded the limestones and marks the division line between the Silurian and Devonian. It is the principal period of deformation in the region before the great Appalachian revolution which came at the close of the Paleozoic.²

Siluride movements following the extensive Silurian sedimentation were especially prominent in the higher northern latitudes.

¹ Charles Schuchert, "Paleogeography of North America," *Bull. Geol. Soc. Am.*, XX (1910), 491, 540.

² M. R. Campbell, *Bull. Geol. Soc. Am.*, V (1894), 189-90.

In the Yukon region of Alaska, according to Brooks and Kindle, it seems probable that one of the recurrent epochs of crustal disturbances took place in early Devonian or late Silurian times, for all the rocks laid down before this period appear to fall into the metamorphic class, though they have suffered a varying amount of alteration. Granitic intrusions are associated with this folding and it is probable that this epoch was closed by an uplift followed by erosion.¹

In northeast Greenland, what appears to be an orogenic movement at the close of the Silurian has been recognized and described by Nathorst as follows:

The Silurian strata, as we have seen, are folded and compressed and partly metamorphosed. If this bears any relation to the formation of a mountain range, the folding took place before the deposition of the Devonian strata, for the latter show only a relatively slight amount of disturbance. Otherwise it must be surmised that the folding was the result of a depression of the Silurian strata along a fault at their eastern border, or perhaps between such a fault and another which can be imagined as passing west of the present boundary of the Archean.²

This folding in northeast Greenland parallels and may perhaps be related to the great Caledonian folding of Scotland and Scandinavia.

In Europe the close of the Silurian was a time of much greater disturbance. Flexing and faulting of the crust at this time developed a chain of stupendous mountains in northwestern Europe. The present stumps of these great mountains run throughout the length of Scandinavia; reappear in the northwest highlands of Scotland, and extend onward into Ireland, Wales, and England. Evidences of these ancient mountains are to be recognized as far south as Devonshire. To this chain Suess has applied the name Caledonian, recognizing it as one of the greatest ranges of the past.³ Both in Scandinavia⁴ and in the Scottish Highlands⁵ the formation

¹ A. H. Brooks and E. M. Kindle, "Paleozoic and Associated Rocks of the Upper Yukon, Alaska," *Bull. Geol. Soc. Am.*, XIX (1908), 312-13.

² A. G. Nathorst, cited by Willis, *op. cit.*, p. 341.

³ Eduard Suess, *The Face of the Earth*, Sollas trans., II (1906), 82-86; III (1908), 386-99.

⁴ A. E. Törnebohm, "Grunddragen af det Centrala Skandinaviens Bergbyggnad," *K. Svenska Vetensk. Akad. Handl.*, XXVIII (1896), 212.

⁵ B. N. Peach, J. Horne, and others, "The Geological Structure of the Northwest Highlands of Scotland," *Mem. Geol. Survey of Great Britain* (1907), 463-594.

of this range was characterized, not only by sharp folding, but by some of the most remarkable overthrust faulting of which we have any record. The horizontal thrusting amounts to many miles.

According to Lake and Rastall this folding occurred during the Devonian,¹ since it followed the deposition of a portion of the Old Red Sandstone. In Wales this portion passes downward conformably into the Silurian. Sir Archibald Geikie likewise stated that the Old Red Sandstone of Britain consists of two divisions, the lower of which passes down conformably into the Upper Silurian deposits, while the two divisions are separated one from another by an unconformity which makes a great physical and paleontological break.² This break presumably corresponds to the mountain-building.

But Jukes-Browne, writing in 1911, states that some beds which were formerly called Old Red Sandstone are now placed in the Silurian, while the mass which was formerly called "Middle Old Red Sandstone" is now admitted to be the true Lower Old Red, and known from its fish fauna to belong to the Lower Devonian.³ The movement in Wales he places at the beginning of the Devonian,⁴ while the principal physical features of Scotland had been developed between the close of the Ordovician and the opening of the Devonian period. In the southern uplands, where the time limits are more closely drawn, the plication follows the Silurian, for that system is included in the crumpling. The time of deformation is finally summed up by Jukes-Browne: "Thus the first uplift of the outer ranges may have taken place in Silurian time; the date of the central axis we know [apparently close of Silurian] and the final intense development of the pressures in the outer ranges may have occurred either at the same time or even during the actual formation of the lowest Old Red Sandstone."⁵

The Scandinavian portion of this great mountain system apparently affords less definite evidence of the precise time of this disturbance, but Haug concludes that although we cannot, in the

¹ Philip Lake and R. H. Rastall, *Textbook of Geology* (1910), pp. 342-43.

² Sir Archibald Geikie, *Textbook of Geology*, 4th ed., II (1903), 1006-7.

³ A. J. Jukes-Browne, *The Building of the British Isles* (1911), p. 114.

⁴ *Ibid.*, p. 119.

⁵ *Op. cit.*, p. 126.

absence of incontestable Devonian deposits, determine in a precise manner the age of the folding in Scandinavia, we can place it, from the analogy with Scotland, at the junction of the Silurian and Devonian.¹

Holtedahl has noted a northward continuation of the Caledonian mountain-folding in Spitzbergen, but as he found beds which he believes to belong to the uppermost Silurian resting unconformably upon the Silurian strata which are incorporated in the folds, he would place the date of the folding late in the Silurian instead of at its close, which, if correct, would seem to indicate that the disturbance commenced in the northern portion of the Caledonian chain somewhat earlier than it did farther south.²

While there was intense crumpling in the Grampian geosyncline and in Scandinavia along this northeast-southwest Caledonian axis at the beginning of the Devonian, folding also took place, in central Europe, at approximately the same time, along a northwest-southeast axis. The folded belt extends from the Ardennes of France through the Taunus and Thüringerwald into Moravia, where this system of folds disappears under the great overthrusts of the Carpathians, which are of much more recent origin.³ Farther west than the Ardennes, in the Cotentin region of northwestern France, Lecornu has described Siluride folding which may be a westward continuation of this mountain system of central Europe.⁴

In the Sahara Desert recent explorations by Gautier have shown the existence of folding during the Caledonian epoch. The early Devonian strata in the Oran Sahara rest in horizontal or slightly undulating beds upon folded Silurian strata.⁵

According to Hauthal, South America also suffered from deformative movements at this time. In the Sierra de la Ventana, of Argentina, Hauthal found that the older Paleozoic sedimentaries

¹ Emile Haug, *Traité de géologie*, II (1911), 730.

² Olaf Holtedahl, personal communication.

³ Emile Haug, *op. cit.*, p. 732.

⁴ L. Lecornu, cited by Suess, *op. cit.*, IV, 48.

⁵ R. Chudeau and E. F. Gautier, "Sur le structure géologique du Sahara central," *Comptes rendus*, CLXI (1905), 374-76.

were affected by folding which took place between the Silurian and Devonian.¹

Over considerable areas in southeastern Brazil horizontal beds of Devonian age rest unconformably upon folded and metamorphic rocks for the most part of probable pre-Cambrian age, but possibly including some strata representing the Cambrian or Lower Silurian.² This is the most conspicuous period of deformation to which the eastern half of the continent of South America has been subjected since Archean times. It resulted in a great chain of mountains, of which the present Serra do Espinhaço, or Backbone Range of Brazil, represents the roots. The time of the crumpling and faulting has not yet been closely determined, and this cannot yet be classed as a Siluride movement, though Hauthal believes that the Sierra de la Ventana, in which he found evidence of a Siluride movement, are related in origin to the Brazilian Highlands.

In New South Wales, according to Süssmilch, the Silurian period was brought to a close after a long period of sedimentation, by a pronounced deformative movement which folded and elevated the Silurian strata to such an extent that much of the country was raised above sea-level. Incomplete knowledge of the nature and distribution of the succeeding Devonian sediments makes it impossible to form any definite opinion as to the extent of this movement.³ But farther north, in the Narrigundah Gold Field of Queensland, Devonian strata are again found resting horizontally upon folded Silurian beds.⁴

Like the closing stage of the Ordovician, the end of the Silurian period was a time of rather general crustal disturbance which reached extreme intensity in certain regions. Present knowledge is not adequate, and correlations are not sufficiently exact, to determine how nearly simultaneously the disturbances appeared in the

¹ R. Hauthal, "Excursion à la Sierra de la Ventana," *Publicaciones de la Universidad de La Plata*, 1901, pp. 30.

² Hartt, cited by Suess, *op. cit.*, I, 508. J. C. Branner, *Geologia Elementar, Rio de Janeiro* (1906), p. 217.

³ C. A. Süssmilch, *An Introduction to the Geology of New South Wales* (1911), p. 33.

⁴ H. I. Jensen, "The Building of Eastern Australia," *Roy. Soc. Queensland*, XXIII (1911), 165.

different regions; and that is a crucial point. But from available data it would seem that the deformation was in progress at some points as early as the latter part of what has been classed as Silurian, while it persisted at other points into what has been classed as early Devonian. Even if the identifications are strictly decisive, such a range of time for a major deformative movement would not seem more than is to be expected under the hypothesis of a genetic relationship between the movements in widely separated quarters of the globe, for absolute simultaneity is improbable. The critical question, however, lies between the weight that is to be given to the identifications of the dividing line that has been fixed by geologists in their local studies in the cases cited, and that which may properly be given to the diastrophic movements when they shall have received the critical attention that has been given to the stratigraphic and paleontologic criteria. If a real discrepancy is found ultimately, which class of evidence shall give way to the other?

DEVONIDES

In North America the most noteworthy orogenic disturbances connected with the Devonian period occurred near its close in eastern Quebec, New Brunswick, Maine, and perhaps also south-westward through the tract of Appalachia which was rather disposed toward upward movements during the Paleozoic. In the Gaspé Peninsula of Quebec the Bonaventure conglomerate of late Devonian, or early Mississippian, age was laid down unconformably upon the vertical edges of the Silurian and Devonian strata about Percé.¹ The Devonian and older strata have been thrown into pronounced folds of the Appalachian or Jura type, indicating that a conspicuous mountain range was developed here after the deposition of these Devonian strata. The youngest formation included in the folded mountains is the Gaspé sandstone, which has been correlated by Clarke with the Hamilton of New York.² The great folds of Gaspé therefore arose some time between the late Hamilton and the beginning of the Mississippian, with the evidence tending

¹ J. M. Clarke, "Early Devonian History of New York and Eastern North America," *Mem. New York Mus.*, No. 9 (1908), 92-102.

² J. M. Clarke, *op. cit.*, pp. 86-88.

to show that the disturbance came within the later Devonian rather than at its close.¹

These movements apparently also affected a portion of Nova Scotia, for in the MacArras Brook region, according to Ami, the Lower Carboniferous strata rest unconformably upon the upturned edges of the Lower Devonian of that region.² Though the folding is here less definitely located than in Gaspé, both foldings would seem to be manifestations of the same diastrophic disturbance.

Evidences of the same uplift and folding are to be looked for in Appalachia. Following the black Hamilton shales from New York to southern Virginia there occurs a great volume of sandy shale and argillaceous sandstone comprising the Jennings and Hampshire formations of Maryland, or the Chemung and Catskill of New York. Willis has estimated that if this mass of sediment could be restored upon a sea-level plain corresponding in shape and size to Appalachia, it would produce a mountain range closely resembling in height, extent, and mass the Sierra Nevada of California.³ These he calls the Devonian Highlands. Their elevation would follow the Hamilton and thus correspond closely in time with the folding period in Gaspé.

At the close of the Devonian much of the continent of South America stood out of water.⁴ In northeastern Argentina, to the west of the Cerro del Agua Negra, Bodenbender found the thick Devonian formations unconformably overlain by red Permo-Carboniferous sandstones.⁵ The time of this movement has not been as yet closely determined.

But the greatest Devonide movements which have yet been recognized are those of Australia. The close of the Devonian was one of the greatest mountain-making epochs of New South Wales, according to Süssmilch—of such importance, indeed, that the name

¹ *Ibid.*, pp. 14-15.

² H. M. Ami, "Meso-Carboniferous Age of the Union and Riversdale Formations, Nova Scotia," *Bull. Geol. Soc. Am.*, XIII (1902), 533.

³ Bailey Willis, "Paleozoic Appalachia or the History of Maryland during Paleozoic Time," *Maryland Geol. Survey*, IV (1902), 61-62.

⁴ Charles Schuchert, *Jour. Geol.*, XIV (1906), 738.

⁵ G. W. Bodenbender, *Boletín de la Academia Nacional de Ciencias de Cordova*, XV (1897), 201.

Kanimbla epoch has been suggested for this mountain-making period.¹ Süssmilch states that the folding must have taken place either at the close of the Devonian, for the Devonian beds are infolded, or, at the latest, early in the Carboniferous, for the Devonian strata had been greatly eroded before the horizontal Permian-Carboniferous strata were laid down. The general movements were on such an extensive scale as to convert the greater part of New South Wales into land. The folding was accompanied by batholithic intrusions.

In northwestern Europe, where accumulated strains had been relieved by such an extensive and remarkably vigorous crustal deformation at the close of the Silurian, the Devonian and early Carboniferous periods were a time of comparative quiescence. Devonian movements, however, have been recognized along a belt which, beginning in Brittany, includes the Armorican massif, the basin of Saarbrück, the Vosges, Black Forest, Thüringerwald, and continues into lower Silesia. These movements occurred either at the dividing line between the Devonian and the Lower Carboniferous, or very early in the latter period.²

Suess also implies that this chain may be related to one in the southern Tian Shan Range in central Asia, where an unconformity with folding at the base of the Lower Carboniferous represents an east-and-west line of Devonian wrinkling.³ A possible connecting link between these widely separated wrinklins is suggested by Boutscheff's observations in the Balkans, northeast of Sophia, where steeply overfolded Upper Silurian graptolite beds are covered unconformably by the Culm.⁴ But the age of this folding is not closely limited.

CULMIDES

The Lower Carboniferous or Mississippian period seems to have been one of comparative quiescence, as implied by the extensive formation of limestone which characterizes this portion of the

¹ C. A. Süssmilch, *An Introduction to the Geology of New South Wales* (1911), pp. 51-52.

² Emile Haug, *op. cit.*, p. 831.

³ Eduard Suess, *The Face of the Earth*, Sollas trans., IV (1909), 2.

⁴ S. Boutscheff, cited by Suess, *op. cit.*, p. 16.

earth's history in so many parts of the globe. But at the close of the period there was a widespread withdrawal of the sea. In North America the seas retired from a large part of the United States, New Brunswick, and Nova Scotia, to such an extent that when the sea again advanced in the Pennsylvanian or Upper Carboniferous period, the new sediments were laid down unconformably upon the eroded Mississippian beds over wide areas. This unconformity at the top of the Mississippian, or at the base of the Millstone Grit, is continued very widely throughout most of the interior and western states and an unconformity at about this same horizon appears also at various points in Alaska.¹ It was chiefly because of the unconformity which occurs at this horizon over such wide areas, not only in North America, but in other continents as well, that the portion of the Carboniferous below the unconformity was urged as a separate period under the name Mississippian.

Distinct folding movements occurred in the Arbuckle region of Oklahoma. Near the close of the Mississippian or beginning of the Pennsylvanian, the rocks of the Arbuckle region were folded and the western part thrown into mountains. Faulting also occurred on a large scale.² As a result of the elevation of these mountains at this time, with the attendant acceleration of erosion and rapid clastic sedimentation, the sediments of the succeeding Pennsylvanian period have reached a thickness in the adjacent portion of Arkansas of 18,000 feet.³ These Arkansas Coal Measures correspond to only a lower part of the Pennsylvanian.⁴

In Europe conditions were somewhat similar. De Lapparent states that there was considerable volcanic activity from the Armorican region to the Vosges together with a complete withdrawal of the sea from the region, at the close of the Dinantian, or Lower Carboniferous. At this time there was energetic folding in the Vosges on the eastern frontier of France, while evidences of

¹ A. H. Brooks and E. M. Kindle, "The Paleozoic Section of the Upper Yukon, Alaska," *Science*, XXV (1907), 182.

² J. A. Taff, "Geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma," *Prof. Paper*, 31, U.S. Geol. Survey (1904), p. 37.

³ T. C. Chamberlin and R. D. Salisbury, *Geology*, II (1906), 562.

⁴ A. J. Collier, "The Arkansas Coal Field," *Bull.* 326, U.S. Geol. Survey (1907), p. 24.

similar orogenic disturbances are seen in the Laval coal basin on the borders of Brittany¹ and also in the Sudetes.² The Culm occupies a large area in southern Portugal. But the Upper Carboniferous of that country is very restricted in area and rests unconformably upon the rocks below, probably indicating a Culmide movement.³

Asia also shows evidences of mild disturbances, at least, following the Culm. In Hseng King, the southern province of Manchuria, Inouye states that the Upper Carboniferous is unconformable upon the Lower.⁴ In the southern portion of the Tian Shan range in central Asia the Lower Carboniferous, according to Suess, is marked by unconformities with orogenic movements both above and below it.⁵ The Lower Carboniferous shows folding which took place before the basal beds of the Carboniferous were laid down. The inference naturally drawn from Suess is that this folding occurred before the beginning of the Pennsylvanian, but from Keidel's original description the first beds to be deposited upon the truncated folds are to be correlated with the uppermost Carboniferous of Europe.⁶ Hence the folding may have taken place either at the close of the Culm or before the Stephanian of the Pennsylvanian period. From the fact that strong folding was so general a phenomenon in many of the neighboring ranges of central Asia in the middle of the Carboniferous period, it is possible that this folding in the Tian Shan occurred also at that time, and so would be a Westphalo-Carbonide movement.

WESTPHALO-CARBONIDES

The closing of the Paleozoic era was accompanied by much diastrophism. Though sometimes referred to as a more or less continuous period of disturbance from mid-Carboniferous times till the close of the Paleozoic, a closer analysis seems to show that

¹ A. de Lapparent, *Traité de géologie*, 5th ed., II, 906.

² Eduard Suess, *op. cit.*, II, 69.

³ K. G. Jane, *Encyc. Brit.*, 11th ed., XXII (1911), 135.

⁴ K. Inouye, cited by Suess, *The Face of the Earth*.

⁵ Eduard Suess, *op. cit.*, IV (1909), 2.

⁶ Hans Keidel, "Geologische Untersuchungen im südlichen Tian Schan nebst Beschreibung einer obercarbonischen Brachiopodenfauna aus dem Kukurtuk-Tal," *N. Jahrb. f. Min.*, XXII, Beilage Bd. (1906), pp. 266-384.

there were at least two distinct periods of deformation, separated by a period of comparative quiescence. The first stage of disturbance falls at the close of the Westphalian epoch, and hence may take the name of Westphalo-Carbonide movement. At this time extensive warpings and folding affected large portions of central and southern Europe and gave rise to a notable series of mountains which are grouped under the names Armorican and Variscan chains,¹ or collectively the Hercynian system,² and sometimes designated the Paleozoic Alps.³

The area of Armorican folds has a breadth reaching from Bristol, England, on the north, to La Vendée on the south, a distance of 330 miles across the strike.⁴ This broad belt was crumpled into a succession of parallel folds trending east and west. They extend from the Atlantic shores of South Ireland, Cornwall, and Brittany eastward through the Ardennes, Vosges, Schwarzwald, Taunus, Harz, Thüringerwald, Frankenwald, Erzgebirge, and on into the Sudetes and Carpathians and are probably continuous, beneath younger formations, with the Carboniferous chains among the Balkans, and with the folds of the same age in Dobrudja, near the Black Sea,⁵ a really great range of mountains of which we have today only the stumps remaining.

It is generally agreed that the chief episode in the formation of this great mountain system occurred between the deposition of the Westphalian and that of the Stephanian series. On the north side of the chain—in the south of England, in the Ardennes, in the Harz, and in Westphalia—the folding follows the Westphalian, but as the Stephanian is absent from this belt the date of the folding cannot be closely determined, though it is certainly before the Saxonian which inaugurates the Permian transgression.⁶ But in the central plateau, the principal orogenic movements antedate the Stephanian which rests directly upon the Dinantian and older

¹ Eduard Suess, *The Face of the Earth*, Sollas trans., II (1906), 86–III.

² Marcel Bertrand, "La chaîne des Alpes, et la formation du continent Européen," *Bull. Soc. Géol. France*, 3d Ser., XV (1887), 435–40.

³ Emanuel Kayser, *Geologische Formationskunde*, 2d ed. (1902), p. 174.

⁴ A. J. Jukes-Browne, *op. cit.*, pp. 178–88.

⁵ Emile Haug, *op. cit.*, p. 830.

⁶ *Ibid.*, p. 831.

rocks which are generally metamorphosed. In the basin of Laval (Mayenne) the Stephanian Coal Measures with a conglomeratic base lie unconformably upon overfolded Westphalian beds.¹

Contemporaneously there occurred several belts of disturbance in England somewhat apart from the main range. Here are included the Lancastrian flexures and the folding of the Pennine range, sometimes called the backbone of England. The folding is pre-Permian and appears to have come rather late in the Carboniferous period. From the immense amount of rock material which must have been removed from the broad arch of the Lake District before the Permian sandstones were laid upon it, Jukes-Browne suggests that this erosion possibly occupied the whole of Stephanian time, thus making this folding of the same date as the Armorican flexures.²

The Malvern and Abberley Hills are but the worn-down remnants of a mountain chain which was formed in the limited interval between the deposition of the Lower and Upper Coal Measures.³ According to Groom, this folding and faulting was essentially contemporaneous with that of the Hercynian system. This would seem to be so if the Upper Coal Measures of Britain are equivalent to the Stephanian, as they are given by Geikie.⁴ But according to Jukes-Browne, the Stephanian is absent from England and the Hercynian disturbance came after the English Upper Coal Measures.⁵ If this be the correct correlation, the formation of the Malvern and Abberley Hills would seem to have been accomplished slightly earlier than that of the main Hercynian system.

On the border line between Italy and Austria the Carnic Alps result from east-and-west plications which are referred to Carboniferous times, but the precise stage remains doubtful. The principal Paleozoic movements in the exterior chains of the western Alps as well as in the eastern Alps are referred to this period with similar qualification.⁶

¹ A. J. Jukes-Browne, *op. cit.*, p. 188. ² *Ibid.*, pp. 189-92.

³ T. T. Groom, "On the Geological Structure of Portions of the Malvern and Abberley Hills," *Quart. Jour. Geol. Soc.*, LVI (1900), 176-95.

⁴ Sir Archibald Geikie, *Textbook of Geology*, II (1903), 1051.

⁵ A. J. Jukes-Browne, *op. cit.*, p. 171. ⁶ Emile Haug, *op. cit.*, pp. 830-31

Also in the Pyrenees there was a stage of folding at about this time. In the Asturias, and doubtless in the greater part of the Iberian Peninsula, folding movements followed the Westphalian, coming probably before the Stephanian, but in any case before the Permian. From Galicia in the extreme northwest corner of the peninsula and from the north of Portugal, a number of nearly parallel folded ranges, closely packed, run southeastward into the great Meseta and continue as far as the valley of the Guadalquivir in southern Spain.¹ This intensely folded mountain system includes much of the Carboniferous together with much granite which, for the most part, was intruded during the Carboniferous period. As in the Asturias, here also the upper beds of the Carboniferous rest unconformably on the folded region, and the general structure of these mountains thus dates, like that of the Armorican and Variscan systems, from late in the Carboniferous period.

South of the Mediterranean there are evidences of Hercynian movements as far as the African Caledonian fold zone.² In the Atlas Mountains of Morocco the age of the closing Paleozoic folding has not been fixed more closely than between the close of the Lower Carboniferous and the beginning of the Permian. But in eastern Morocco and in south Oranais, the Devonian, Dinantian, and Moscovian (Westphalian) are found in concordance just as in Spain, which has led Haug to conclude that they belong to the same geosynclinal and to the same zone of folding.

In South Africa the most definite bench mark for correlation is afforded by the base of the Karroo System—the Eccra series, and especially its basal formation, the Dwyka conglomerate. Its widespread occurrence, its distinctive petrographical characteristics, and the fact that, while conformable in the south of Cape Colony with the uppermost member of the Cape System, it shows a varying degree of unconformity elsewhere, make the Dwyka conglomerate an excellent datum level.³ In the north of Cape Colony, according to Hatch and Corstorphine, in Natal, Zululand, Rhodesia,

¹ Eduard Suess, *The Face of the Earth*, Sollas trans., II (1906), 126.

² G. B. Flamand and E. F. Gautier, cited by Haug, *op. cit.*, p. 831.

³ F. H. Hatch and G. S. Corstorphine, *The Geology of South Africa*, 2d ed. (1909), p. 335.

Orange River Colony, and in the Transvaal, the Dwyka conglomerate rests unconformably upon the older rocks, generally upon the strata of the Cape System.¹

The age of the Cape System is still somewhat uncertain; the middle member (Bokkeveld series) is of Devonian age, but the age of the upper member (Witteberg series) is more in doubt, as these beds have as yet yielded no remains of animals, and only rather poor specimens of plants. While little value can be placed upon the determinations, it is to be noted that all the genera found occur in the Carboniferous rocks of Europe.² Hatch and Corstorphine are also inclined to correlate the Witteberg series with the Carboniferous of the Northern Hemisphere.³ The Ecca series is of Permo-Carboniferous age, but until more is known about the age of the strata involved in the folding this widespread break in South Africa cannot well be correlated with movements elsewhere. But it would be most natural to suppose that the glaciation (represented by the Permo-Carboniferous Dwyka conglomerate) followed closely upon the deformation.

In North America movements which appear to be contemporaneous with the Hercynian folding of Europe at the close of the Westphalian have been recognized at a number of points. Very pronounced movements affected portions of Oklahoma. The Arbuckle Mountains, which had suffered Culmide folding, were again subjected to strong folding before the close of the Pennsylvanian. Taff states that this deformation commenced near the beginning of Upper Carboniferous time and ended before its close.⁴ Hutchison describes the major portion of the present structure of the region of the Arbuckle and Criner Hills as formed in early mid-Carboniferous times.⁵ The date of the folding, while occurring some time within the Pennsylvanian period, cannot as

¹ F. H. Hatch and G. S. Corstorphine, *op. cit.*, pp. 335-38; also Plate I, opposite P. 33.

² A. W. Rogers and A. L. DuToit, *An Introduction to the Geology of Cape Colony*, 2d ed. (1909), pp. 159-60.

³ Hatch and Corstorphine, *op. cit.*, p. 344.

⁴ J. A. Taff, "Geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma," *Prof. Paper 31, U.S. Geol. Survey* (1904), p. 38.

⁵ L. L. Hutchison, *Bull. 2, Oklahoma Geol. Survey* (1911), p. 7.

yet be closely located. But rocks of very late Pennsylvanian or early Permian age have been deposited across the western end of the Arbuckle uplift. They lie in a nearly flat position across the eroded edges of several thousand feet of the Pennsylvanian, all of the Mississippian, Devonian, Silurian, and a large part of the Ordovician rocks.¹ The folding of the Wichita Mountains is thought by Taff to have occurred simultaneously with that of the Arbuckle uplift.²

Some movements, though they do not appear to have been very pronounced, affected the extreme eastern border of the continent. In the southeastern part of New Brunswick the strata of the Upper Carboniferous³ (or Permo-Carboniferous)⁴ rest unconformably upon the Millstone Grit at various points. These movements may possibly have affected also the eastern side of the Appalachians farther south, but the intense deformation which developed the Appalachian Mountains, as now known, came later.

In the Appalachian region, according to David White, there is distinct evidence of a shift in the region of sedimentation or, in other words, a change in the direction of warping of the Appalachian trough at the close of the Westphalian time; for during the Westphalian the maximum subsidence and loading was toward the south, in which region no Stephanian was ever deposited, while in the northern Appalachian region, the greater part of which was exposed during most of the Westphalian time, there occurred the maximum deposition of Stephanian with possibly lack of interruption in its passage into the Permian.⁵

In addition to the better-known cases of mountain development, there are several movements of this general age which cannot be placed very closely with the data now at hand. According to Evans, the eastern Andes of Bolivia, which had been folded in very early times and had again been brought beneath the sea, received

¹ J. A. Taff, *op. cit.*, pp. 35-36.

² *Ibid.*, p. 80.

³ R. W. Ells, *Geol. Survey of Canada, Ann. Rept.*, I (1885), 7, 29 E.

⁴ L. W. Bailey, "Report upon the Carboniferous System of New Brunswick," *Geol. Survey of Canada*, XIII (1902), 19 M.

⁵ David White, personal communication.

renewed elevation late in the Carboniferous period.¹ Kayser is authority for the statement that the folding of the Urals began late in the Carboniferous and reached its height in the Permian, and, even as far as Armenia and central Asia, evidences of folding and mountain-building movements at about this time have been recognized.² Farther east, in the southern Tian Shan range, Keidel has recognized pronounced foldings which occurred within the Carboniferous period. The Lower Carboniferous sandstones and shales had been greatly folded and considerably eroded before the Schwagerina-bearing limestone was laid down upon the truncated folds. The Schwagerina limestone, which is correlated with a similar formation in the Urals, belongs to the uppermost part of the Pennsylvanian.³ Whether this movement is a Culmide or a Westphalo-Carbonide is therefore not yet determined, but because movements of the latter class were so widespread along this general east-and-west axis it may not improbably prove to belong to this group.

Further studies in the heart of the continent should add much to the subject of Carboniferous diastrophism, for the broad mountainous zone between central Siberia and the Tertiary chains in south Asia is made up of ranges whose principal folding appears to date from about the middle of the Carboniferous period, which suggests that they may be the homologues of the Armorican and Variscan chains of Europe.⁴ The Altai and the chains of Trans-Baikalia make up one series so assigned; another begins in the Kuen Lun and follows the Nan Shan to the chain of northern China; and another is the Tsing Ling Shan and the mountains of northern Szechuan where Baron von Richthofen found folding at

¹ J. W. Evans, "Expedition to Caupolican Bolivia, 1901-1902," *Geog. Jour.*, XXII (1903), 633-34.

Isaiah Bowman, "The Physiography of the Central Andes," *Am. Jour. Sci.*, 4th Ser., XXVIII (1909), 376.

² Emanuel Kayser, *Geologische Formationskunde*, 2d ed. (1902), p. 174.

³ Hans Keidel, "Geologische Untersuchungen im südlichen Tian Schan nebst Beschreibung einer obercarbonischen Brachiopodenfauna aus dem Kukurtuk-Tal," *N. Jahrb. f. Min.*, XXII, Beilage Bd. (1906), pp. 282-83.

⁴ Emile Haug, *op. cit.*, p. 834.

the close of the Carboniferous, together with great eruptions of igneous rock which were presumably associated with the movements.¹

PERMO-CARBONIDES

In the two preceding sections an endeavor has been made to separate the Culmides and Westphalo-Carbonides out of the great group of diastrophic movements that marked the close of the Paleozoic. It remains to assemble the movements that took place following the Permo-Carboniferous sedimentation. But here the time of the diastrophism can be less definitely located, and the correlations less closely made than in the case of the Westphalo-Carbonides. Recognizing this difficulty the term Permo-Carboniferous is quite widely in use in various parts of the world, and as this is in reality a period of transition from the Paleozoic to the Mesozoic, this terminology has its advantages, and the name Permo-Carbonides will be used to designate the final set of disturbances which mark the break between the two eras.

One of the most familiar as well as one of the most pronounced of the Permo-Carbonide movements was the folding of the Appalachian Mountains of North America. The principal folding of the Appalachians followed the laying-down of the Dunkard sediments, which are the youngest strata involved in the folds. The age of the Dunkard beds was identified as Permian by Fontaine and White in 1880,² and this has been very commonly accepted since. But David White states that the flora of the Dunkard shows it to be transitional between Carboniferous and Permian, and that its uppermost portion corresponds approximately to the lowest member of the Rothliegende of Europe.³ This reference of the greater part of the Dunkard to the Lower Rothliegende he believes to be well founded. This would bring the main folding of the Appala-

¹ Bailey Willis, *Research in China*, I, Pt. I (1907), 297.

² W. M. Fontaine and I. C. White, "The Permian or Upper Carboniferous Flora of West Virginia and Southwestern Pennsylvania," *Second Geol. Surv. of Pennsylvania, Report of Progress, PP.* (1880), pp. 105-20.

³ David White, "Permian Elements in the Dunkard Flora," *Bull. Geol. Soc. Am.*, XIV (1903), 538-42.

chians after the Carboniferous and after a portion, at least, of the Permian, and it may not have followed immediately after the deposition of the Dunkard.

The time of the Appalachian folding seems to have been also an epoch of general epeirogenic movements. At this time much of the eastern half and of the interior of North America was uplifted and aqueous sedimentation largely stopped. Much of this region was never again the site of notable sedimentation.

In South America also a general movement of emergence seems to have been in progress at this time. Katzer places the withdrawal of the sea from the lower Amazon region within the Permian. Schuchert states that the sea retreated from this region "at the close of Neo-Carbonic time," and that thereafter the interior of this extended land, as far as observations will permit judging, was not again subjected to marine deposits.¹

In Australia minor deformative movements are said to have occurred in New South Wales during the Permo-Carboniferous period, while Süssmilch states that at its close renewed orogenic movements of a more pronounced sort took place in the same region.² At this time the folding extended sufficiently far southward to develop a series of broad anticlinal and synclinal folds in the Permo-Carboniferous strata along the northern edge of the Maitland coal field where the folding is believed to have produced an elevation of at least 7,000 to 8,000 feet.³ The axis of the folding is north and south, parallel to the present coast. This was the last folding in New South Wales; subsequent movements have been of the epeirogenic sort.

In eastern Europe it was not until late in the Permian that folding is said to have taken place on the site of the Russian geosynclinal. All members of the Carboniferous, and some of the Permian, thus form a thick concordant series. In the Donetz basin, the Upper Permian was affected by the folding.⁴

¹ Charles Schuchert, "Geology of the Lower Amazon Region," *Jour. Geol.*, XIV (1906), 725.

² C. A. Süssmilch, *op. cit.*, p. 102.

³ *Ibid.*, p. 121.

⁴ Emile Haug, *op. cit.*, p. 834.

The close of the Permian in western Europe seems to have been accompanied by a general uplift. In most parts of England there is a certain amount of unconformity between the Permian and the Bunter, or Lower Triassic, but it does not indicate any great tectonic disturbance, though in the northern and central portions of England there was some tilting of the Permian beds as well as some faulting in the interval.¹ In the Hercynian chain, the last movements took place at the close of the Permian, according to Haug. From them arises the discordance observed in the southern Vosges and in the central plateau of France between the Upper Permian and the Lower Triassic.² In the southern portion of the central plateau, especially in the basin of Gard, the most intense foldings of the Hercynian system came after the Stephanian, and in the Alps of Savoy the Permian also is often found to have been included in the pre-Triassic folding.³

A Permo-Carbonide movement also affected the southern Tian Shan range in central Asia. The youngest member of the Paleozoic sedimentary series in this region, according to Keidel, is a conglomerate containing pebbles from the Schwagerina (Permo-Carboniferous) limestone formation.⁴ This conglomerate has resulted from an upbowing of the range, and associated with it is a discordance. Resting upon the conglomerate are the Angara beds which are classed as Triassic, though Keidel is inclined to believe that their lowest layers should be placed in the Paleozoic. But if diastrophism be followed as the basis of correlation the break between Paleozoic and Mesozoic would naturally come somewhat lower—at the discordance.

GENERAL

From this brief assemblage of data bearing upon the periodicity of the diastrophism during the Paleozoic era, it appears that the orogenic disturbances of the more pronounced type fall quite generally into distinct groups; that these groups are well separated from one another; and that the disturbances of each group were more or less widely distributed over the globe, and that they had their

¹ A. J. Jukes-Browne, *op. cit.*, p. 215.

³ *Ibid.*, p. 831.

² Emile Haug, *op. cit.*, pp. 917-18.

⁴ Hans Keidel, *op. cit.*, pp. 356-57.

active stages at about the same time, so far as correlations now permit one to judge. It appears also from this study, that the current divisions into periods which represent the general judgment of geologists as to what are natural divisions, and which are based on various considerations largely stratigraphic and paleontologic, are in fair accord with the divisions that would be made if diastrophism were chosen as the primary basis of division. Such general accord was to have been expected if diastrophism is a true and fundamental basis for such division, but some divergencies in detail were also naturally to be anticipated.

The chief divergencies that have been found are the debatable division line between the Cambrian and the Ordovician, and the partially accepted separation of the old Carboniferous group into Mississippian, and Pennsylvanian. It is notable that these division lines are those that have been regarded as the least satisfactorily established. Since the famous controversy of Murchison and Sedgwick the Cambro-Ordovician dividing line has been a subject of debate, and of uncertainty and oscillation of judgment. The breaking-up of the old Carboniferous period and the recognition of the lower portion as a distinct period under the name Mississippian is a matter of recent date and is only partially accepted. There is evidence of distinct diastrophism at the close of the Mississippian, but from present data it does not seem to be of the same order of magnitude and prevalence as the deformations that mark off the other periods, with the exception of the mooted Cambro-Ordovician diastrophism.

The Westphalo-Carbonide movement is brought by diastrophic studies into more prominence than was given it under the criteria that have been in common use.¹ It appears to have been unusually widespread and pronounced. On account of its magnitude, dynamically and geographically, it seems entitled, under the diastrophic view, to be made to mark the beginning of the closing scenes of the Paleozoic era. Shortly following it, and perhaps in

¹ De Lapparent, however, states that while formerly it was thought proper to put the coal beds all in one undivided period, one is now forced to observe that the coal formations are traversed, between the Westphalian and the Stephanian, by an orogenic phenomenon of such importance that it should be of greater weight than all else in determining the limit of the systems (*Traité de géologie*, 5th ed., II [1906], pp. 889-90).

consequence of it, came the extraordinary Permo-Carboniferous glaciation, attended by biological changes of so pronounced a nature that they have generally been regarded as the initiation of the distinctive types of life of the Mesozoic era. The Permo-Carboniferous events that followed the Westphalo-Carbonide movement have been growing into recognition in recent years as indicating a time of transition from the Paleozoic to the Mesozoic. These studies give support and definiteness to that idea.

Thus it appears that the division of Paleozoic time on the basis of diastrophism, so far as present data go, does little violence to the systems and time divisions already formed on stratigraphic and paleontologic and other grounds, while it seems to throw distinct light on the remarkable phenomena that closed the era, phenomena over which not a little obscurity long has hung.